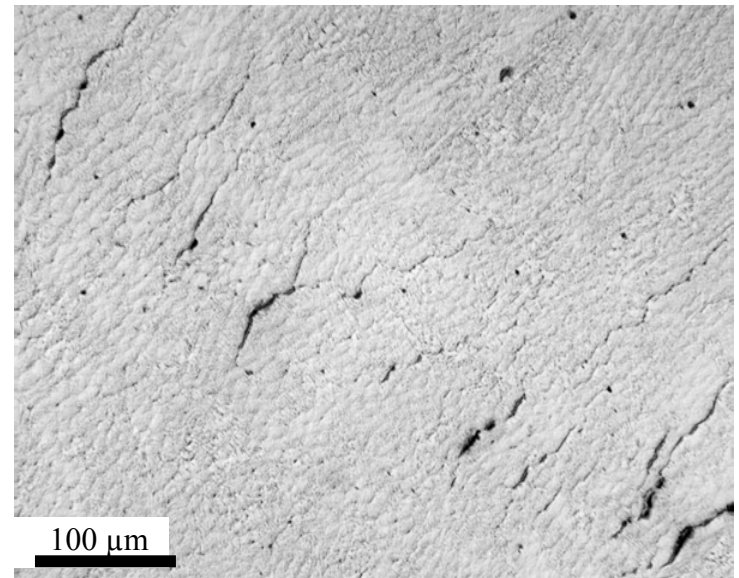


# Unique Solidification Cracking Mechanism in Ultra-Low Interstitial Iron and Iron Alloy Weld Metal

Jack H. Devletian, Portland State University, DMR Award #9972052

- Why solidification cracking in low-C steel welds?  
Not expected from existing theories
- Solidification cracking of iron alloys and austenitic stainless steel by varestraint testing
- Unique cracking mechanism of low C steel is promoted by:
  - $\delta/\gamma$  transformation stresses
  - Segregation due to Fe-C peritectic
- Effects of C on solidification cracking are complex and non-linear
  - Cracking peak at  $\sim 0.1\%C$
- Grain boundaries are preferred cracking sites (photo), followed by dendrite/cell boundaries
- Important for modern welding consumables to join ships, bridges, nuclear and other structures.



Solidification cracking in Fe-0.1C weld metal  
produced by trans-varestraint test

## Notes:

In this study, 30-lb vacuum melted ingots of “model” Fe-C, Fe-Ni, Fe-B and Fe-C-Ni alloys were prepared for solidification cracking tests. In addition, commercial steels, such as AISI 1018 steel and 304 austenitic stainless steel, were also evaluated for comparison. These cracking tests included both the longitudinal vareststraint and the trans-vareststraint tests. From these tests, the fundamental “brittleness temperature range” can be obtained. Since the model alloys contained virtually no impurities (S, P, etc), the roles of C, Ni, B and O could be evaluated and compared to their behavior in commercial steel weld metal.

Previous theories of solidification cracking of steels predicts a linear relationship between C or Ni content and cracking susceptibility. In this work, the effect of C on solidification cracking is very non-linear. In fact, there is a major cracking peak at ~0.1%C. This is related to both the peritectic Fe-C reaction and the transformation stress due to the delta-to-austenite phase transformation. When Ni is added to Fe, cracking susceptibility is nearly linear. However, when Ni is added to Fe in the presence of C, there is a non-linear interaction between Ni and C. The addition of B always promotes solidification cracking in Fe and Fe alloys.

The reason why this work is so important to the welding industry is because these are the typical compositions that are be used as filler metals for common processes such gas tungsten arc, shielded metal arc, gas metal arc and flux cored arc welding. For example, the commercial gas metal arc welding filler metal ESAB AWS ER70S-3 contains Fe-0.1C and ESAB’s ER70S-2 contains Fe-0.06C. These and virtually all modern steel filler metals contain the C levels that are not immune to cracking (as predicted by the “old” equations).

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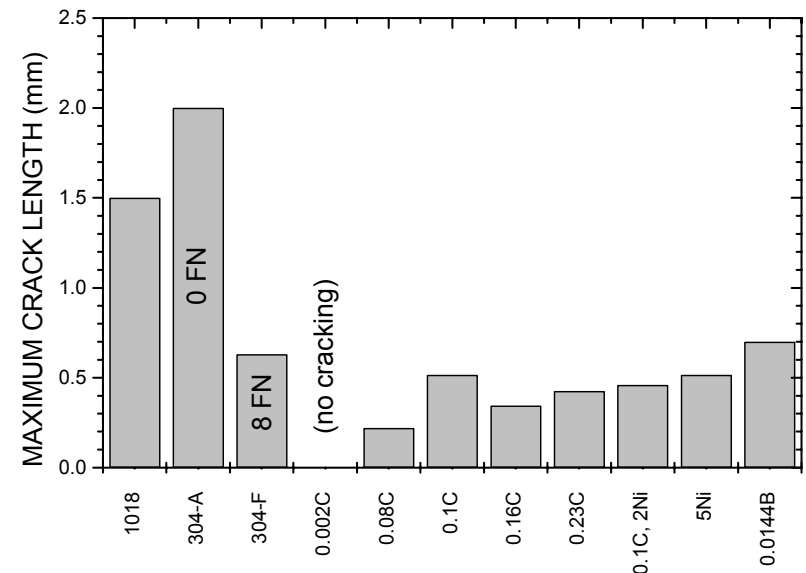
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## Training:

- 1 graduate student:  
R. Borden received MS degree
- 1 post-doc:  
Dr. Shankar Venkataraman, from Indira Gandhi Centre for Atomic Research, Kalpakkam, India

## Outreach:

- J. Devletian incorporates research results in welding classes at Portland Community College
- Presents welding experiments showing cracking susceptibility of steels and stainless steels (figure) to two technical high schools in Portland, OR



Comparing solidification cracking of iron alloys and austenitic stainless steels

This exciting project was started at Oregon Graduate Institute (OGI) and subsequently transferred to the Mechanical Engineering Department at Portland State University. In the process of closing OGI, the materials science department was seamlessly transferred to Portland State University. All of the research activity and most of the equipment were also transferred to Portland State University.

Mr. Ross Bordon was the graduate student working on this project at OGI and subsequently received his MS degree in Materials Science & Engineering from OGI.

Upon transferring to Portland State University, I received permission from Dr. Bruce MacDonald to hire a post-doc to continue Ross Bordon's work. Dr. Shankar Venkataraman took a temporary leave of absence from the Indira Gandhi Centre for Atomic Research to work on this challenging project. Dr. Venkataraman did his MS research with me at OGI in 1986 on the welding of austenitic stainless steel. He continued his stainless steel research at IGCAR as well as for his PhD thesis at the IIT Madras. Thus, Shankar was the "ideal" person to work on this project because he understood solidification mechanics and could provide the link between solidification cracking in austenitic stainless steels with that observed in iron alloys.

Regarding outreach, I am actively involved with Portland area technical high schools (Marshall high and Benson high) in upgrading their math and science appreciation. I give presentations to their welding technology classes on the cracking mechanisms in steels and stainless steels. Similarly, I help write the welding curriculum for the welding department at Portland Community College. Once a year, I teach "Welding 101" and exposed the welding technology students for fundamental aspects of solidification mechanics.

NSF project terminates in July, 2003. Shankar and I are currently preparing papers for consideration for publication. Next year's work will include continued microstructural effects of solidification by using auger electron spectroscopy to isolate any segregation causing cracking. Applying this fundamental data to commercial welding will relate our research with actual welding fabrication.